XV. *An Experimental Inquiry undertaken with the view of ascertaining whether any, and what signs of current Force are manifested during the organic process of Secretion in living animals* (continued). *By* H. F. Baxter, *Esq. Communicated by Dr.* Todd, *F.R.S.*

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In drawing up the former paper, published in the Transactions for 1848, the author experienced some difficulty, inasmuch as the subject of these researches presents a mixed character; and conscious that strong objections might be reasonably started by the physical philosopher to conclusions deduced from experiments of the following nature, he has naturally felt some hesitation in presenting the following communication to the Society. As no attempt, that he is aware of, has been made to refute the former conclusions by *experimental* evidence, it only remains for him to state that he has treated the subject more as a physiologist, and for physiologists, than for physicists; that he has not considered himself called upon to refute every objection the physical philosopher might be supposed to raise; and that he has endeavoured at the same time to avoid every thing of a controversial character.

Precautions.—Instead of entering fully into all the precautions necessary to be observed in researches of the following description, we shall refer to the works of Faraday*, Matteucci† and Becquerel‡. We must however bear in mind that it is not the mere fact of getting an effect upon the needle of the galvanometer that is to satisfy us; *that* can be readily obtained: we have to point out to what class of phenomena the effects may be referred.

As it appeared desirable to condense the experiments as much as possible, we shall make a few general remarks as to the mode in which the experiments were performed. The whole arrangement was ascertained to be in a good working condition previous to each set of experiments. As an objection might be started to the use of the former electrodes, two others were procured of platinum wire, No. 16 gauge, each a foot in length, and from the same piece of wire. Smaller wooden mercurial cups were also used, and it was at these cups that the making and breaking of contacts were made. The extremities of the electrodes were well cleaned after and previous to the formation of each circuit; moreover, the electrodes were held lightly in the hand, not squeezed.

* Experimental Researches in Electricity, vol. ii. p. 60.

† Traité des Phénomènes Électro-Physiologiques, chap. iii.

‡ Traité de l'Électricité, tome iv. p. 164.

§ 1. *On the manifestation of Current Force during Biliary Secretion.*

Experiment 1.—Rabbit. Prussic acid dropped on the eye. One electrode inserted into the gall-bladder; the other in contact with the blood flowing from the vena cava inferior in the chest; the latter positive* 10°, and by breaking and making contact made to increase. Between the blood in the vena porta and the bile; blood slightly positive. Mucous membrane of stomach and blood in the chest; stomach positive 8°. The circuit between the gall-bladder and the blood in the chest was again formed; blood positive 10°.

Experiment 2.—Rabbit. Prussic acid dropped on the eye. As the results were similar to those obtained in the last experiment we need not repeat them.

The parts were allowed to remain for half an hour, when the following circuits were formed:—Between the surface of the liver and blood in the chest; no effect. The mucous membrane of the gall-bladder and blood in the chest; blood positive 3° or 4°. The mucous membrane of gall-bladder and the wall of the chest, out of the way of the blood; no effect.

Experiment 3.—Cat. Prussic acid, swallowed. Between the bile in the gall-bladder and blood flowing from the vena porta; the latter slightly positive. Between the bile in the gall-bladder and blood flowing from the vena cava inferior, in the chest; the latter positive 5°.

Experiment 4.—Cat. Prussic acid, swallowed. The electrodes were inserted into the gall-bladder and vena cava inferior in the chest; the latter positive 4° or 5°, and as the blood flowed out from the wound the motion of the needle increased. Between the gall-bladder and vena porta, the latter slightly positive.

Several other experiments might be related proving the same conclusions, but as the fact may not be disputed, we shall state, in a general manner, the other circuits that were formed; viz. between clots of blood and pieces of liver; between the mucous membrane of the intestines and the gall-bladder; between the blood in the chest and various parts of the abdomen; one electrode was coated with bile, and then both of the electrodes were dipped into the blood in the chest. It was generally found that the electrode in contact with the blood was *positive*, but not always; sometimes vibrations of the needle only occurred, at other times the needle went as far as 80° or 90° and then stopped. The motions of the needle presented quite a different character to those observed when the bile in the gall-bladder and the blood flowing from the vena cava inferior were formed into a circuit; the latter presented a steady character, they could be depended upon; whereas with the former a greater effect might be produced at first, and it would then cease, or perhaps go in the opposite direction.

The following fact may not perhaps be denied, viz. *that when the electrodes of a galvanometer are brought into contact with the bile flowing from the liver and with*

* If zinc and platinum be formed into an elementary voltaic circle with dilute sulphuric acid, the *current*, according to the usual mode of expression, goes from the zinc through the acid to the platinum; the platinum is therefore the *positive* electrode, and in contact with the *cation* hydrogen.

the venous blood flowing from the liver, we obtain evidence of the secreted product and the blood being in opposite electric states.

Can we refer these effects to any known actions? And

First. To the *heterogeneity of fluids.* Let us first ascertain what we mean by the phrase *heterogeneity of fluids*, otherwise it will serve as a convenient cloak for our ignorance. According to the researches of BECQUEREL, during the reaction of two liquids upon each other, that which performs the part of an *acid*, takes positive, that of an *alkali*, negative electricity. From the experiments we have just related, we find that the electrode in contact with the blood is *positive.* Are we then in a condition to say that the blood is *acid* to the bile, and that the effects are due to the *combination* of the blood with the bile? Where do they combine? Where are the acting points in the circuit? According to all chemical analyses the blood is supposed to contain a *free alkali*, and it is said that the bile contains acids, such as the *choleic*, or *bilic* acids, &c. If then we are to refer the effects to the heterogeneity of the fluids, we must consider the blood as acid, and not only that, but that immediately after the *separation* of the secreted product *from* the blood it immediately *recombines* with the blood.

Let us however just assume, according to the idea, first, we believe, entertained by WOLLASTON, that the effects are analogous to those which occur in the cell of a voltaic circuit, viz. to those of *decomposition*, and we shall now find that the results obtained with the galvanometer confirm this view. The electrode in contact with the *cation* (alkali) in a voltaic circuit is *positive*; if then we suppose that the blood contains the *cation* and the bile the *anion*, we should naturally expect that the results upon the galvanometer would be such as do occur. As this is the point to be proved, we shall now leave it and notice one or two other circumstances to which the effects may be referred; and

Secondly. To *catalytic actions*, or *the combining power of platinum.* We have strong experimental reasons for believing that when blood escapes from a wound it enters into *combination* with the oxygen of the atmosphere; when a plate of platinum therefore is in contact with the blood, actions similar to those which occur in the gas-battery take place. We have a right to suppose that similar actions would occur at the other electrode, namely, that in contact with the bile; still, it might not necessarily follow that the latter would counteract the effects of the former. Judging then from the *direction* of the current, the effects may be fairly supposed to be due to the actions which occur between the atmosphere and the blood, or, in other words, to *catalytic actions.*

There can be no doubt that the effects observed are partly due to *catalytic actions*, and we may even go further and say, that they *must* be so as a necessary consequence. We could not wish for a stronger confirmation of our views: just now we were obliged to suppose the blood to be *acid*—to contain an *anion*—to account for the effect; now we are obliged to suppose it to contain a *cation*—to be alkaline—to account

for the catalytic action, or if not in an alkaline state, still in such a state as to combine readily with the oxygen of the atmosphere. Now, this latter state we are necessarily driven to entertain, when supposing, which no physiologist will deny, that the blood, during secretion, undergoes a change similar to that of *decomposition**.

We shall now speak of,

Thirdly. *Thermo-electric actions.* BECQUEREL† and BRESCHET, as is well known, have shown that different parts of a living animal are of different temperatures; but it must be borne in mind that their experiments were intended to elucidate thermo-electric actions, and might not, therefore, be considered as comparable with the present. Although it would be considered rather a stretch of the imagination to suppose that the effects can be referred to thermo-electric actions, since no effect was obtained when the electrodes were inserted into the vena porta and hepatic veins, as in former experiments, or even in the experiments of MULLER, between the corresponding arteries and veins, still, it is for physiologists to show that the effects cannot be referred entirely to these actions. The following experiments may, therefore, be considered as worthy of being recorded.

A porcelain jar, 2 inches and a half in diameter and the same in depth, capable of holding about five ounces and a half of fluid, was used as the external cell; a portion of the small intestines of a rabbit, capable of holding half an ounce of fluid, was suspended by threads and formed the internal cell; the ends of the electrodes, to the extent of half an inch, were bent at a right angle and placed in each cell, the other extremities being connected with the galvanometer and mercurial cups as in the experiments on animals. Thus arranged, water at different temperatures was poured into each cell.

Experiment 1. Temperature of atmosphere . . . . . 71°
Temperature of water in external cell 68
Temperature of water in internal cell 120

Slight vibrations of the needle. Every endeavour to obtain a greater effect failed. The temperature of the fluid in each cell was then ascertained by means of a delicate thermometer.

Temperature of internal cell . . . . . 105°
Temperature of external cell 80

Experiment 2. Temperature of external cell . . . . . 160°
Temperature of internal cell 68

Vibrations as before; and it was then found that the

Temperature of external cell was . . . . . 125°
Temperature of internal cell 98

* It is not necessary for us to point out in what manner, whether by parent-cells or secreting-cells.

† Traité de l'Électricité, tom. vii. p. 20.

Experiment 3. Temperature of external cell . . . . . 67°
Temperature of internal cell 130
Vibrations; and
Temperature of external cell . . . . . 81°
Temperature of internal cell 110

In whatever manner the experiments were varied, whether by using water at greater or less differences of temperature, similar results were obtained. The vibrations were sharp and quick at the commencement, but soon terminated; in no instance could a decided effect upon the needle be obtained by making and breaking contact, and the effects were not in any way similar to those observed in the animal body. There is one remark, however, which might be made in reference to these experiments, viz. if we could keep the two fluids at constant temperatures at the point of contact, more decided effects might be expected.

Before we dismiss the subject of thermo-electric actions, we ought, perhaps, to relate some experiments in which a resistance—a liquid conductor—was added to the circuit, and see if the current would be capable of traversing it. We shall relate these experiments further on, and for the following reasons, assuming for a moment that the current would be arrested, we should not then be justified in coming to the conclusion that they are *therefore* due to thermo-electric actions; and our object is, as we have stated before, to ascertain if possible the *existence*, not the *force* of the current.

§ 2. *On the manifestation of Current Force during Urinary Secretion.*

Experiment 1.—Rabbit. Prussic acid dropped on the eye. One electrode in contact with the mucous surface of the ureter, the other inserted into the renal vein of the left kidney; no effect. One electrode inserted into the urinary bladder, the other into the renal vein of the right kidney; the latter slightly positive. There was great difficulty in catching the vibrations of the needle.

Experiment 2.—Rabbit. Prussic acid dropped on the eye. One electrode inserted into the bladder, the other into the left renal vein; the latter positive 5°: the latter electrode was then placed on the surface of the intestines; no effect.

After a short time similar circuits were formed between the bladder and the right renal vein; no effect.

Experiment 3.—Cat. Prussic acid, swallowed. Between the bladder and left renal vein; the latter positive 8°.

Experiment 4.—Cat. Prussic acid, swallowed. Between the bladder and both renal veins; the latter slightly positive.

Bladder much distended: urine acid to litmus.

Experiment 5.—Cat. Prussic acid, swallowed. Between left renal vein and blad-

der, the former positive 5°: the electrode in contact with the bladder was then placed on the surface of the intestines; blood slightly positive.

Experiment 6.—Rabbit. Prussic acid dropped on the eye. Between the bladder and left renal vein; the latter positive 3°: the electrode in contact with the vein was then placed on the surface of the intestines in the neighbourhood of the kidney; the electrode in contact with the bladder was now positive, slightly. The circuit between the vein and bladder was reformed; no effect. Between the right renal vein and bladder; no effect.

Bladder full: urine acid to litmus.

To what other conclusion can we arrive at, than that, *during urinary secretion, the blood and urine are in opposite electric states*? The effects are but small, certainly, amounting perhaps only to 3° or 4°; but such as they are they indicate the blood to be *positive*. Considering the small size of the organ, the nature of the secretion, *acid*, and the transient effects that are produced, we may feel some surprise at obtaining such satisfactory evidence.

In judging of the results upon the needle, we must take into consideration the *acting points* in the circuit; we have at least three acting points in the circuit; viz. at the point of secretion, and at the two electrodes. Although we are led to suppose that the current consequent upon the actions which occur at the point of secretion and those which occur at the electrode in contact with the blood assist each other, nevertheless the current consequent upon the actions which occur at the other electrode may be of such a nature as to counteract the effects of the two former, depending, in a great measure, upon the nature of the secretion. Hence we should be led to very erroneous conclusions if we judge merely from the effect upon the needle, either as to the *force* of the current, or its *origin*. We have also some reasons for supposing that the flowing of the blood through the organ would have some influence, acting by *convection** or carrying power. We might also add, that the very circumstance of a difference being observed, as to the amount of deviation of the needle in the different organs, would indicate that the effects cannot be due to one and the same cause, for instance, to thermo-electric effects.

§ 3. *On the manifestation of Current Force during Mammary Secretion.*

We have, unfortunately, only one experiment; the results however may be considered of some value.

A Cat. Prussic acid, swallowed. Unaware at the time that the cat was suckling, one of the mammary glands was divided whilst opening the walls of the abdomen. One electrode was placed in contact with the milk, the other in contact with the blood flowing from one of the mammary veins; blood positive 8°.

We should not be justified in coming to any definite conclusion from the result of one experiment, and therefore defer making any remarks.

* Faraday, Experimental Researches, vol. i. p. 496.

§ 4. *On the manifestation of Current Force during Respiratory Actions.*

Whether the changes which take place in the lungs between the atmosphere and the blood, or whether the evolution of carbonic acid be considered as of the same nature as a secretion, may be a disputed point. The question, however, as to the *state* of the arterial blood is one of extreme interest, inasmuch as we have hitherto found the venous blood to be in a *positive* state to the secretions,—with the exception to the secretion in the stomach in rabbits, as related in former experiments; and the effects here may be reasonably considered as due to the predominant actions which occur at the electrode in contact with the mucous membrane of the stomach; —with this exception, we have found the *venous* blood *positive*. We have found the blood flowing from the portal vein to be *positive* to the bile, and in reference to the liver the portal vein may be considered as its artery; we can hardly consider the blood in the portal vein to form the *cation* to the bile, but look upon the effects as due to the blood being in contact with the *cathode*. We must bear in mind, that, *in order to obtain* CURRENT FORCE, *the* CIRCUIT FORM *must be given to the arrangement**; *i. e.* that the electrodes must be brought into contact, or by means of some conducting mass, with the ANION and CATION *originating* the power. The solution of the following question, viz. *What will be the effect if we apply one electrode in contact with the mucous membrane of the lungs, and the other in contact with the blood flowing from it*, i. e. *arterial blood*? is one of some importance.

Experiment 1.—Rabbit. Pithed. An opening was made in the lower part of the trachea and the chest laid open.

One electrode inserted into the right bronchus, the other into the left ventricle; the latter positive 4° or 5°, by making and breaking contact made to increase.

Between the right bronchus and right ventricle; the latter slightly positive.

The former circuit was reformed; no effect.

Experiment 2.—Rabbit. Pithed. In opening the chest the left subclavian vein was wounded. One electrode in contact with the right bronchus, the other with the blood from the vein; a very slight effect.

Between the right bronchus and left ventricle; the latter positive 2° or 3°, by making and breaking contact made to increase.

Experiment 3.—Rabbit. Prussic acid dropped on the eye. Between the left bronchus and the right ventricle; the latter positive 2° or 3°.

Between the left bronchus and left ventricle, a sudden effect upon the needle occurred, but soon became slight; blood positive.

Experiment 4.—Rabbit. Prussic acid dropped on the eye. Between the left bronchus and the right ventricle; the latter positive 3° or 4°.

Between the two ventricles; a slight effect occurred, sometimes in one direction, sometimes in the other.

Experiment 5.—Rabbit. Prussic acid dropped on the eye. Between the two ven-

* FARADAY, Experimental Researches, vol. ii. p. 51.

tricles; no effect. The electrode in contact with the right ventricle was inserted into the right bronchus; effect very slight; blood positive.

Experiment 6.—Cat. Prussic acid, swallowed. Between right bronchus and left ventricle; the latter positive 5°. Between the two ventricles; no effect.

Experiment 7.—Cat. Prussic acid, swallowed. Between left bronchus and the axillary vein, which was wounded in opening the chest; no effect. Between left bronchus and left ventricle; the latter positive 3° or 4°.

There was one circumstance worthy of notice; when the electrodes were inserted into the ventricles, blood did not necessarily escape from the wound upon being withdrawn.

We might relate several other circuits that were formed, viz. between blood on each side of the chest, or between blood in the chest and blood in the abdomen; but as no definite conclusion could be deduced from them, we think it unnecessary. Other experiments might also be related all tending to the same conclusion, viz. *that when the mucous membrane of the lungs and the blood flowing from the same part are formed into a circuit, the arterial blood is positive.*

When considering that the effects might be thought due to *catalytic actions*, we alluded to the changes which occur when *venous* blood is exposed to the atmosphere, to account for its being in a *positive* state. How can we apply the same reasoning to *arterial* blood? In every case it was not exposed to the air; but when exposed, should we be justified in concluding that it would again undergo the same changes which it had immediately undergone in the lungs?

In concluding our remarks in reference to the electric *state* of arterial blood, it is with some degree of pleasure that we can now look back upon our former failures, and which at that time were a source of extreme annoyance,—we allude to our endeavours to obtain evidence of *current force* by forming a circuit between the portal and hepatic veins. Pouillet and Muller had already failed to obtain any effect by inserting the electrodes into corresponding arteries and veins*. Not only were we looking in the wrong quarter for our current, but we now find that the arterial and venous blood are *both* in the same electric state, and thus accounting for our failures.

In the following experiments a resistance was added to the circuit. A glass tube,

* We do not deny, but think it highly probable, that with *delicate* galvanometers some effect might occur. Assuming that a slight effect were obtained, it would then become a question whether the effects were not due to the changes which occur at the electrodes, rather than at the points of nutrition or secretion. The physical philosopher has an undoubted right to call upon the physiologist to point out the *anion* and *cation* in his circuit, or some adequate *cause* for the *current*. The fact is, the vagueness associated with the term *current* has misled physiologists. We are firmly convinced, that, without extreme care, a delicate galvanometer would only lead to confusion; there is no difficulty in obtaining an effect upon the needle; if anything, we obtain more than we want: the great point is to account for it when obtained, *i. e.* to show with what class of phenomena the effects may be referred.

nearly half an inch in diameter and 3 inches in length, was bent thus, **U**, and contained water; one limb was connected with one of the mercurial cups by a piece of copper wire of the same thickness as those connected with the galvanometer, and 3 inches in length; the other limb of the tube was connected with another mercurial cup by a similar piece of copper wire; each of these wires dipped, to the extent of a quarter of an inch, into the water. We thus had a resistance consisting of a column of water, nearly half an inch in diameter, 2 inches and a half in length, and 6 inches of copper wire. By this arrangement we could easily cause the current to travel through the galvanometer, with or without the resistance, at pleasure, by merely dipping the electrodes into one mercurial cup or the other, and without any loss of time.

Experiment 1.—Rabbit. Pithed. Between renal vein and bladder; *with* resistance, vibrations; *without*, 3° or 4°: *with*, vibrations; *without*, vibrations.

Between left bronchus and left ventricle; *with* resistance, no effect; *without*, 4°: *with*, 2° or 3°; *without*, no effect.

Between gall-bladder and blood from vena cava inferior; *with* resistance, 5°; *without*, 8°: *with*, 5°; *without*, 10°. The motion of the needle with the resistance was slow and steady.

Experiment 2.—Rabbit. Pithed. Between right bronchus and left ventricle; *without* resistance, 2° or 3°; *with*, vibrations; *without*, vibrations.

Between gall-bladder and blood from vena cava inferior; *without*, 10°; *with*, 3° or 4°; *without*, 10°.

Between renal vein and bladder; no effect either *with* or *without* the resistance.

We shall not attempt to deduce any conclusions from these experiments as to the *force* of the current, and leave it for the physical philosopher to decide whether the effects can be due to thermo-electric actions.

It might have been necessary to have made a few observations before we conclude our present paper, as to the difficulties we have to encounter in our inquiries; some very valuable remarks, however, have been already made by an eminent physical philosopher in reference to the development of electricity in the vegetable kingdom, and as they are so applicable to our present purpose we cannot do better than quote them:—"Il est démontré," says Becquerel, "que l'hétérogénéité des differents sucs qui se trouvent dans les tissus, est la cause première du dégagement de l'électricité, et que l'on doit y joindre encore les altérations qu'ils subissent au contact du platine et de l'air. Il est à regretter que les phénomènes observés ne puissent être mesurés; mais il y a impossibilité de le faire: essentiellement variables de leur nature, parce qu'ils sont modifiés à chaque instant par des agents extérieures, et d'autres causes que nous ne pouvons apprécier, leur existence seule peut être constatée. Au surplus, la physiologie parvient rarement à mesurer les effets qu'elle observe, tant ils sont fugitifs*."

Conclusion.—We are almost tempted to make a few remarks in reference to the

* Becquerel, Bibliothèque Universelle de Genève. Juin 1851.

nature of the *forces* concerned in the process of *secretion*; as it might, however, be considered premature to do so, we shall defer our observations to a future opportunity, and conclude by merely drawing attention to the resemblance first suggested, we believe, by WOLLASTON, between the *polar* decompositions which occur in the decomposing cell of a voltaic circle and the process of secretion in living animals.

The facts which the experiments related in the present paper tend to establish are as follows:—

First. That, during biliary secretion, the *bile* and *venous blood* flowing from the hepatic veins are in *opposite* electric states.

Secondly. During urinary secretion, the *urine* and *venous blood* flowing from the renal vein are in *opposite* electric states.

Thirdly. During mammary secretion, the *milk* and the *venous blood* flowing from the mammary veins are in *opposite* electric states. And,

Lastly. That when a circuit is formed between the *mucous membrane* of the lungs and *blood* (*arterial*) in the left ventricle of the heart, we obtain evidence of *current* force.